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REVIEW

A review of the recent development, challenges, and opportunities of electronic waste (e-waste)

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Abstract
This study reviews recent developments, challenges, and the prospect of electronic waste (e-waste). Various aspects of e-waste, including collection, pre-treatment, and recycling, are discussed briefly. It is found that Europe is the leading collector of e-waste, followed by Asia, America, Oceania, and Africa. The monetary worth of e-waste raw materials is estimated to be \$57.0 billion. However, only \$10.0 billion worth of e-waste is recycled and recovered sustainably, offsetting 15.0 million tonnes (Mt) of CO_2. The major challenges of e-waste treatment include collection, sorting and inhomogeneity of waste, low energy density, prevention of further waste, emission, and cost-effective recycling. Only 78 countries in the world now have e-waste related legislation. Such legislation is not effectively implemented in most regions. Developing countries like south-eastern Asia and Northern Africa have limited or no e-waste legislation. Therefore, country-specific standards and legislation, public awareness, effective implementation, and government incentives for developing cost-effective technologies are sought to manage e-waste, which will play an important role in the circular economy.

Keywords E-waste · Pre-treatment · Recycling · Legislation · Circular economy

Introduction

New products of information and communications technology (ICT) and other e-products are being introduced continuously into the current market, while previous products are swiftly becoming obsolete (Awasthi and Li 2017). The amount of e-waste produced is, therefore, rapidly increasing every year. E-waste is primarily described as the waste generated by all parts and items of electronic and electrical equipment (EEE) that have been discarded without the intention of being reused (Baldé et al. 2016). It is also known as waste electrical and electronic equipment (WEEE) and e-scrap in different parts of the world (Mary and Meenambal 2016). E-waste encompasses a diverse range of electronic devices, such as telecommunications and information technology equipment, large household items, lighting equipment, automatic dispensers, medical devices, monitoring and control devices, as well as consumer electronics, including electronic and electrical tools, sports and leisure equipment, toys, mobile phones, and computers (Huang et al. 2014; Chen et al. 2015a).

Advanced lifestyle, technological advancement, and worldwide economic progress have led to the ever-increasing generation of e-waste, leading to a significant environmental

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and health concern (Matsakas et al. 2017; Bhuiya et al. 2020). Over two billion metric tonnes of waste are produced globally, with e-waste accounting for 53.6 million tonnes (Statista 2010). Global e-waste has been rising very sharply, with a total generation of 53.6 Mt in 2019, increasing by 21% since 2015 (Tiseo 2021). Around 83.0% of the total e-waste generated in 2019 was not documented and hence likely to be burnt openly or dumped illegally (Statista 2010; Balde et al. 2017), which causes a serious threat to human health and the environment. The remaining 17% of e-waste was collected and properly recycled in 2019. In a continent wise comparison of generating e-waste, Asia was the highest generator (46.4% in the world) in 2019, followed by America (24.4%), Europe (22.4%), Africa (5.4%), and Oceania (1.3%) (Forti 2020). Although Asia was the highest e-waste generator among the continents, it generated far less waste per inhabitant (5.6 kg/inh) compared to Europe (16.2 kg/inh), Oceania (16.1 kg/inh), and the Americas (13.3 kg/inh), due to a large number of inhabitants (4.40 billion) in the region. However, the lowest e-waste generator was in Africa with 2.5 kg/inh (Forti 2020).

Recycling e-waste is a valuable source of raw material as it comprises a wide range of materials like metals, glass, and plastics (Fig. 1). However, only 17.4% of global e-waste is collected and recycled due to the complexity of collection and recycling (Forti et al. 2020). Recycling e-waste is a difficult task because e-waste consists of metals with different physicochemical properties, including hazardous halogens metals (Ilankoon et al. 2018a). If the substances containing these hazardous compounds are not properly disposed of, they may cause an environmental threat (Chen et al. 2015b; Lu et al. 2015; Rucevska et al. 2015). Proper waste management techniques and the safe disposal of e-waste have become a global priority to mitigate human health risks and environmental degradation caused by landfilling (Song and Li 2015).

E-waste recycling processes such as open burning, metal acid stripping, acid baths, and incineration can produce by-products like heavy metals, furans, and dioxins (Dai et al. 2020). While resource recovery through e-waste can provide employment and commercial prospects, its management may be hindered by inadequate infrastructure and efficient scientific technologies (Lakshmi and Raj 2017). As a result, e-waste management in the twenty-first century is regarded as one of the biggest global challenges, posing serious threats to the environment and human health (Bhutta et al. 2011; Moletsane and Venter 2018; Magalini 2016).

Many researchers have reviewed the literature on e-waste, with some authors focusing on a specific location; for example, Andeobu et al. (Andeobu et al. 2021) investigated the generation of e-waste and environmental management in Asia Pacific countries, while (Meem et al. 2021) studied the environmental and health consequences of electronic waste disposal in Bangladesh. In contrast, (Jaibee 2015) provided an overview of e-waste generation and management in Malaysia. Some authors focused on e-waste management techniques, such as Murthy and Ramakrishna (Murthy and Ramakrishna 2022), highlighted the global best practices in E-waste management, emphasising the importance of policy implementation, technology requirements, and social awareness to achieve a sustainable and circular economy. In contrast, (Abdelbasir et al. 2018) reviewed various techniques for recycling the most important metals from the metallic fractions of e-waste.

Ahirwar and Tripathi (2021) and (Doan et al. 2019) proposed some potential solutions for improving e-waste management, reporting the recent global trend in e-waste generation, recycling, and the impact on human health. Gupta

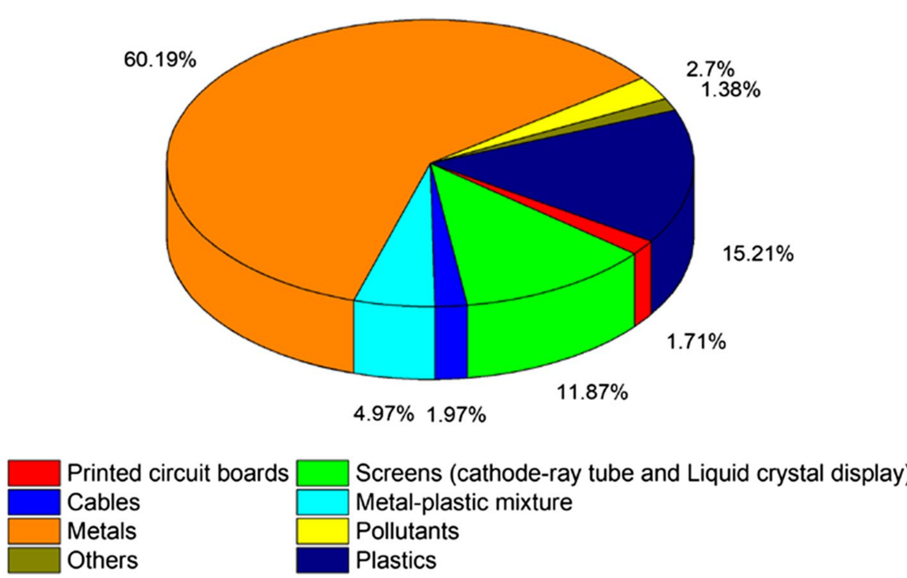

Fig. 1 A typical composition of materials present in e-waste (Ilankoon et al. 2018a)

et al. (Gupta et al. 2014) briefly discussed the negative consequences of hazardous components found in e-waste or created during the recycling process. Pérez-Belis et al. (2015) reviewed the literature from 1992 to 2014, focussing on the genesis, composition, management, and final treatment of e-waste.

Most of the reviews on e-waste in the literature have focused on different aspects, which do not represent the actual picture of e-waste management. Therefore, this review briefly outlined e-waste recycling technologies, including collection, pre-treatment, challenges, and prospects. In this review, the most recent data related to e-waste recycling and management have been reported, which will help researchers and policymakers to make informed decisions.

Types of electronic waste

E-waste can be categorised depending on the origin and purpose of electronic items. There are ten different types of e-waste (Fig. 2) recognised globally (Health and E. Safety 2013; Quinet et al. 2005; Kumar et al. 2018; Faramarzi et al. 2004; European 2012). The average percentage of each category of e-waste can vary depending on many factors, including socio-economic conditions, consumer behaviours, populations, and the dependency of businesses and households on electronic and electrical equipment (EEE) (Balde et al. 2017). Nonetheless, large household items are the leading contributor (42.1%) to e-waste, followed by IT and telecommunication (33.9%), consumer devices (13.7%), and small household equipment (4.7%) (European 2012). Other categories have lesser contributions (< 2% for medical, lighting, electrical, and electronic tools while < 1% for automatic dispensers, toys, sports, monitoring, and control devices) (European 2012) for better readability. In developing countries, e-waste is mainly dominated by TVs, computers, and mobile phones (Needhidasan et al. 2014; Kalia et al. 2021; Nnorom and Osibanjo 2008).

Recycle and recovery of e-waste

Recycling and recovering e-waste are critical aspects of e-waste management that involve economic, environmental, and health-related benefits. E-waste is a resource only if it is recycled and precious materials are recovered. The following sections describe the collection and treatment of e-waste.

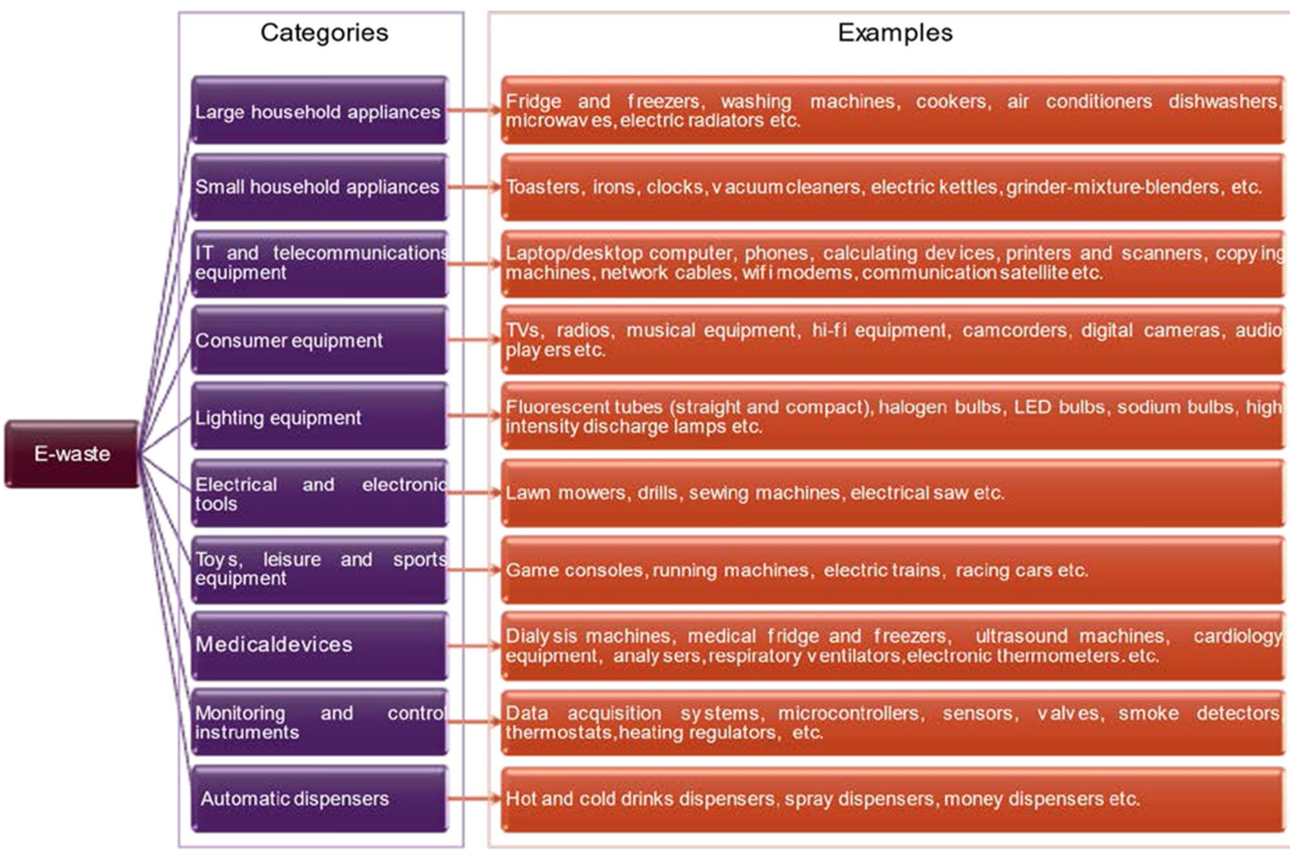

Fig. 2 Types of e-waste and common examples (Health and E. Safety 2013)

Collection

As the first step of e-waste waste management, waste generated by households and businesses is collected (Wath et al. 2010). The second stage of waste management is the pre-treatment before they are sent to treatment centres or dumping sites. The collection processes can be one of the four ways: (a) the official take-back system, (b) mixed residual waste, (c) collection outside the official take-back system for countries with developed waste management, and (d) collection outside the official take-back system for countries without developed waste management (Balde et al. 2017; Nnorom and Osibanjo 2008; Alam et al. 2022; Tanskanen 2013; Ilankoon et al. 2018b; Khanna et al. 2020). In the first category, e-waste is collected by the designated collectors or government bodies such as councils or producers under the national e-waste laws (Balde et al. 2017; EPA-NSW 2022; Sthiannopkao and Wong 2013). This is the ideal way to collect e-waste where pre-treatment processes are applied before sending it to state-of-the-art treatment facilities for recovering useful materials.

The second collection category refers to mixed residual waste, where consumers dispose of e-waste in bins with other household or business waste (Balde et al. 2017; Kumar et al. 2017; Otto et al. 2018). The e-waste collected in this process has a low chance of separation and is likely to be burnt in incineration or dumped with other waste. In the third category, e-waste is collected by registered individual waste dealers or companies and then sell the e-waste to recycling companies (Balde et al. 2017). This system is known as the "collection outside the official take-back system". Finally, countries with no e-waste legislation, such as Bangladesh, manage their electronic waste in unorganised ways, such as informal collectors and recyclers with no central planning and control of e-waste (Islam et al. 2016).

Table 1 shows e-waste collection, estimated values of useful materials in the waste, and their corresponding collection methods in different regions of the world. In 2019, Europe was the leading collector of e-waste (5.1 Mt, 42.3% of its total e-waste) with an estimated value of $5.48 billion. The second-best collector was Asia, which collected 2.9 Mt (11.7%), followed by Americas 1.2 Mt (9.4%), Oceania

Table 1 E-waste collection scenarios in different regions of the world in 2019 (adapted from (Forti 2020))

Region	Collection amount (Mt)	Estimated value (USD)	Collection method
Europe	5.10 (42.3%)	5.48 billion	Formal collection by private operators and municipal councils
Eastern Europe	0.7 (23%)	–	
Northern Europe	1.4 (59%)	–	
Southern Europe	0.9 (34%)	–	
Western Europe	2.1 (54%)	–	
Americas	1.20 (9.4%)	1.30 billion	(a) Formal collection by private operators (b) Informal collection by individual registered companies
Caribbean	0.001 (1%)	–	
Northern America	1.2 (15%)	–	
Central America	0.04 (3%)	–	
South America	0.03 (3%)	–	
Asia	2.90 (11.7%)	3.07 billion	(a) Formal collection by private operators (b) Informal collection by individual registered companies (c) Non-registered informal collectors and recyclers
Western Asia	0.2 (6%)	–	
Central Asia	0.01 (5%)	–	
Eastern Asia	2.7 (20%)	–	
Southern Asia	0.04 (0.9%)	–	
South-Eastern Asia	0 (0%)	–	
Oceania	0.06 (8.8%)	0.06 billion	(a) Formal collection by private operators (b) Informal collection by registered companies
Australia and New Zealand	0.06 (9%)	–	
Melanesia	0 (0%)	–	
Micronesia	0 (0%)	–	
Polynesia	0 (0%)	–	
Africa	0.03 (0.9%)	0.03 billion	Mostly non-registered informal collectors and recyclers
Eastern Africa	0.004 (1.3%)	–	
Middle Africa	0.0001 (0.03%)	–	
Northern Africa	0 (0%)	–	
Southern Africa	0.02 (4%	–	
Western Africa	0.002 (0.4%)	–	

0.06 Mt (8.8%), and Africa 0.03 Mt (0.9%). Globally, the money value of current e-waste generated is $57.0 billion. However, only $10 billion worth of e-waste is recycled and recovered in an environmentally friendly manner, saving 15.0 Mt of CO_2 (Forti et al. 2020).

The collection method in different regions is primarily evolved by their legislation, e-waste management infrastructures, economic conditions, and public awareness (Forti 2020). Most developing countries like south-eastern Asia and Northern Africa, where it is limited or no e-waste legislation, have no record of their e-waste statistics (Balde et al. 2017). Governments in these regions rely on unprivileged and self-employed people to collect and recycle e-waste. These people collect the e-waste from consumers' homes through door-to-door activities, separate the items themselves, and finally sell the separated items to city vendors to be refurbished or recycled (Balde et al. 2017; Islam et al. 2016). Although this option is the worst choice due to its inherent risks to human health and low collection and management, still these types of informal collection activities are being used by many unskilled individuals to earn and lead a basic life. For instance, Bangladesh's informal collection of e-waste was estimated to be around 0.95 Mt/year (Islam et al. 2016). It was also estimated that many small-scale recycling plants in Dhaka city were able to earn up to $3,410.0/month using informal channels (Islam et al. 2016; Masud et al. 2019).

Pre-treatment and recovery treatment methods

After collecting e-waste, it goes through a pre-treatment process before the final processing in the treatment facilities (Wang et al. 2012). The objective of the pre-treatment process is to separate different useable materials from the bulk of the e-waste mix so that they can be transferred to appropriate recovery treatment plants. The pre-treatment process can be three types: (a) manual dismantling, (b) mechanical dismantling and separation, and (c) a combination of both manual and mechanical processes (Batinic et al. 2018). Manual dismantling often separates hazardous and valuable materials such as PCBs, casing, monitors, and batteries, sometimes labour intensive and costly (Zhang and Forssberg 1998). Mechanical pre-treatment comprises separating metals and non-metals, size reduction, shredding, and crushing (Batinic et al. 2018). It is worth noting that if the e-waste is a complex mix of various equipment and items, it is time and cost-effective to use the combined manual and mechanical pre-treatment processes. In developed countries, pre-treatment mostly comprises semi-automatic (manual and mechanical) separation followed by metal recovery in state-of-the-art units (Kaya 2016).

Manual separation is the dominant method in developing countries, followed by metals recovery in small workshops (Oliveira et al. 2012). Low-intensity magnet drums are commonly used to separate ferrous metals from e-waste, while non-ferrous metals are separated from non-metals using electric conductivity base separation tools (Batinic et al. 2018). Other separation techniques, including the gravity method using airflow or water flow tables and sifting, are also commonly used (Oliveira et al. 2012). Once metals are separated from other materials, they are then transferred to the final recovery stage, where two recovering methods are widely used, namely pyrometallurgy and hydrometallurgy (Sahajwalla and Hossain 2020). The pyrometallurgy technique uses high temperatures to purify and extract metals. Some examples of pyrometallurgy are refining, smelting, combustion and incineration (Kang and Schoenung 2005). On the other hand, hydrometallurgy is concerned with extracting metals from concentrated mixtures or a mixture of different materials using aqueous solutions. In a broader sense, pyrometallurgy is commonly used to extract ferrous metals from e-waste, whereas hydrometallurgy is used for recovering non-ferrous metals, e.g. copper, lead, and zinc (Xia et al. 2017).

Challenges and opportunities

There are many challenges and opportunities regarding e-waste and its management. One of the key challenges is the lack of e-waste legislation. Apart from developed nations, most of developing countries do not have e-waste legislation yet. Until 2014, 61 countries covering 44% of the world population had e-waste legislation (Balde et al. 2017). In 2019, 78 countries had their e-waste legislation covering 71% of the world population. Although the most populous countries in Asia, China and India, have now e-waste legislation, other populous countries (population of > 160 million), such as Pakistan and Bangladesh, do not have any e-waste law at this moment (Balde et al. 2017). However, Pakistan has recently banned importing e-waste from other countries, even though there is a substantial doubt whether the prohibition is fully effective (Imran et al. 2017). On the other hand, Bangladesh, the 8th largest country globally by population (Bank 2020), has been aiming to consider such a law in recent times only. Bangladesh's Department of Environment (DoE) has published draft rules (Hazardous waste management rules, 2019) for restricting the use of 15 hazardous substances in some selected EEE products (Wto 2020).

Even though all necessary legislation is in place for e-waste collection and recycling, it is still challenging to handle and process e-waste due to its complex mix of hazardous, precious, base, and other materials. In general, e-waste comprises 40% metal, 30% plastic polymers, and 30% oxides of different materials (Sahajwalla and Hossain 2020). However, these quantities can vary significantly from country to country due to an uneven mix of EEE in the e-waste. E-waste contains precious materials (Ag, Au, and Pd), base materials (Cu, Al, Ni, Sn, Zn, Fe, Bi, Sb, and In), hazardous materials (Hg, Be, Pb, Cd, and As), halogen materials (Br, F, Cl), and plastics, glass, and ceramics (Sahle-Demessie et al. 2018).

The particular challenge of e-waste management is recovering precious, rare earth, and useable materials while the hazardous materials are taken care of. The hazards in waste management include handling hazardous chemicals such as CFC fluids, polychlorinated biphenyls (PCBs), mercury, machinery safety, manual handling of large items, electrical safety, cuts and abrasion risk, and fire and explosion risk (Defra 2006). Other challenges of e-waste management are the limited number of chemical liquids (eco-friendly) that are approved to be used in e-waste management, lack of infrastructures facilities, thermodynamic limits of separating complex mix of materials leading to cost ineffective recovery challenge, financial and policy supports especially for developing countries, and uneven legislations that vary significantly from country to country (Balde et al. 2017; Sahle-Demessie et al. 2018).

On the other hand, the prospect and opportunities of e-waste are paramount if they are recycled properly. As mentioned earlier, e-waste contains precious metals that can be recovered using the urban mining of e-waste. A typical example of such urban mining is that one metric ton of circuit board can produce up to 1.5 kg of gold and 210 kg of copper (Bazargan et al. 2012). The concentration of precious metals is far better than that of the primary mining from ores. For instance, conventional mining of gold from ore contains 5 g/t (Sahle-Demessie et al. 2018), and copper contains 5.25 kg/t (Bazargan et al. 2012). These numbers demonstrate that gold and copper concentrations in urban mining are 300 and 40 times higher than in ores. Recovering these precious metals can generate significant profits if appropriate business models are applied. It was estimated that the money value of materials in e-waste generated worldwide is three times more than the total economic value of the world's silver mining and larger than the GDP of many countries (Forum 2019).

Another prospect of e-waste management is environmental and human health benefits (Rautela et al. 2021). In modern days, human health and environmental issues are considered a priority agenda (Omisore 2018; UN News 2013). In developing countries, however, e-waste management has never been seen as a serious issue, leading to poor and insecure health and the environment around the dumping sites (Masud et al. 2019). However, adopting and implementing e-waste management strategies, policies, and legislation can improve these conditions drastically.

Conclusion

E-waste comprises metal (40%), plastic polymers (30%), and oxides of other materials (30%). The collection, washing, sorting, pre-treatment, and treatment are the key steps for recycling and recovering e-waste. E-waste consists of three major categories: large household items, IT and telecommunication, and consumer and small household equipment. Currently, Europe is the leading collector of e-waste (5.10 Mt, 42.3% of its total e-waste), followed by Asia (2.9 Mt, 11.7%), America (1.2 Mt, 9.4%), Oceania (0.06 Mt 8.8%), and Africa (0.03 Mt, 0.9%). E-waste contains precious materials, base materials, hazardous materials, and other halogens, plastics, glass, and ceramics. Asia is the highest e-waste generator among the continents. However, Asia generates far less waste per inhabitant (5.6 kg/inh) than Europe, Oceania, and America. Unfortunately, 83% of the e-waste generated globally is not documented, meaning the fate of that e-waste is open burning or illegal dumping, leading to a serious threat to the environment and human health. A collective approach from national and international bodies, including public awareness, is crucial to managing e-waste, which will play an important role in the circular economy.

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References

Abdelbasir SM et al (2018) Status of electronic waste recycling techniques: a review. Environ Sci Pollut Res 25(17):16533–16547

Ahirwar R, Tripathi AK (2021) E-waste management: a review of recycling process, environmental and occupational health hazards, and potential solutions. Environ Nanotechnol Monit Manag 15:100409

Alam T et al (2022) E-waste recycling technologies: an overview challenges and future perspectives. Paradigm shift in E-waste management. https://doi.org/10.1201/9781003095972-10

Andeobu L, Wibowo S, Grandhi S (2021) A systematic review of E-waste generation and environmental management of asia pacific countries. Int J Environ Res Public Health 18(17):9051

Awasthi AK, Li J (2017) Management of electrical and electronic waste: a comparative evaluation of China and India. Renew Sustain Energy Rev 76:434–447

Baldé CP, Wang F, Kuehr R (2016) Transboundary movements of used and waste electronic and electrical equipment: estimates from the European Union using trade statistics

Balde CP et al. (2017) The global e-waste monitor 2017. pp 1–116

Bank W (2020) World development indicators: population

Batinic B, Vaccari M, Savvilotidou V, Kousaiti A, Gidarakos E, Marinkovic T, Fiore S (2018) Applied WEEE pre-treatment methods: opportunities to maximizing the recovery of critical metals. Glob Nest J 20:706–711

Bazargan A, Lam KF, McKay G (2012) Challenges and opportunities in e-waste management. Nova Science Publishers, pp 39–66

Bhuiya MMK et al (2020) Comparison of oil extraction between screw press and solvent (n-hexane) extraction technique from beauty leaf (*Calophyllum inophyllum L.*) feedstock. Ind Crops Prod 144:112024

Bhutta MKS, Omar A, Yang X (2011) Electronic waste: a growing concern in today's environment. Econ Res Int 2011:1–8

Chen M et al (2015a) Comparative study on copper leaching from waste printed circuit boards by typical ionic liquid acids. Waste Manag 41:142–147

Chen M et al (2015b) Lead during the leaching process of copper from waste printed circuit boards by five typical ionic liquid acids. J Clean Prod 95:142–147

Dai Q et al (2020) Severe dioxin-like compound (DLC) contamination in e-waste recycling areas: an under-recognized threat to local health. Environ Int 139:105731

de Oliveira CR, Bernardes AM, Gerbase AE (2012) Collection and recycling of electronic scrap: a worldwide overview and comparison with the Brazilian situation. Waste Manag 32(8):1592–1610

Defra (2006) Guidance on Best available treatment recovery and recycling techniques (BATRRT) and treatment of waste electrical and electronic equipment (WEEE): London

Doan LTT et al (2019) Strategies for E-waste management: a literature review. Int J Energy Environ Eng 13(3):157–162

EPA-NSW (2022) Television and computer recycling in NSW, Environmental protection authority NSW, Available at: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/epa/television-and-computer-recycling-guide-160449.pdf?la=en&hash=07372952DF592C4EEB9F8540B51A6C8B74ABC878. Accessed on 28–03–2022

European P (2012) Directive 2012/19/EU of the European Parliament and of the council on waste electrical and electronic equipment (WEEE)

Faramarzi MA et al (2004) Metal solubilization from metal-containing solid materials by cyanogenic Chromobacterium violaceum. J Biotechnol 113(1–3):321–326

Forti V et al (2020) The global e-waste monitor 2020

Forti V et al. (2020) The global E-waste monitor 2020. United Nations University (UNU), International Telecommunication Union (ITU) and International Solid Waste Association (ISWA), Bonn/Geneva/Rotterdam

Forum WE (2019) We generate 125,000 jumbo jets worth of e-waste every year. Here's how we can tackle the problem

Gupta S et al (2014) A review on various electronic waste recycling techniques and hazards due to its improper handling. Int Refereed J Eng Sci (IRJES) 3(5):05–17

Health and E. Safety (2013) Waste electrical *and* electronic equipment recycling (WEEE)

Huang J et al (2014) Leaching behavior of copper from waste printed circuit boards with Brønsted acidic ionic liquid. Waste Manag 34(2):483–488

Ilankoon I et al (2018a) E-waste in the international context–a review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. Waste Manag 82:258–275

Ilankoon IMSK et al (2018b) E-waste in the international context – A review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery. Waste Manag 82:258–275

Imran M et al (2017) E-waste flows, resource recovery and improvement of legal framework in Pakistan. Resour Conserv Recycl 125:131–138

Islam MT et al (2016) A public survey on knowledge, awareness, attitude and willingness to pay for WEEE management: case study in Bangladesh. J Clean Prod 137:728–740

Jaibee S et al (2015) Review on current status of waste electric and electronic product in Malaysia. Appl Mech Mater 773–774:898–907

Kalia P, Zia A, Mladenović D (2021) Examining country development indicators and e-waste under the moderating effect of country development levels and e-waste policy. Int J Qual Reliab Manag. https://doi.org/10.1108/IJQRM-09-2021-0335

Kang, H.Y. and J.M. Schoenung (2005), Electronic waste recycling: A review of U.S. infrastructure and technology options. Resources, Conservation and Recycling, 2005. **45**(4): p. 368–400.

Kaya M (2016) Recovery of metals and nonmetals from electronic waste by physical and chemical recycling processes. Waste Manag 57:64–90

Khanna R, Mukherjee PS, Park M (2020) A critical assessment on resource recovery from electronic waste: impact of mechanical pre-treatment. J Clean Prod 268:122319

Kumar A, Holuszko M, Espinosa DCR (2017) E-waste: an overview on generation, collection, legislation and recycling practices. Resour Conserv Recycl 122:32–42

Kumar A, Saini HS, Kumar S (2018) Bioleaching of gold and silver from waste printed circuit boards by Pseudomonas balearica SAE1 isolated from an e-waste recycling facility. Curr Microbiol 75(2):194–201

Lakshmi S, Raj A (2017) A Review study of E-waste management in India. Asian J Appl Sci Technol (AJAST) 1:33–36

Lu C et al (2015) An overview of e-waste management in China. J Mater Cycles Waste Manag 17(1):1–12

Magalini F (2016) Global challenges for e-waste management: the societal implications. Rev Environ Health 31(1):137–140

Mary JS, Meenambal T (2016) Inventorisation of e-waste and developing a policy–bulk consumer perspective. Procedia Environ Sci 35:643–655

Masud MH et al (2019) Towards the effective E-waste management in Bangladesh: a review. Environ Sci Pollut Res 26(2):1250–1276
Matsakas L et al (2017) Green conversion of municipal solid wastes into fuels and chemicals. Electron J Biotechnol 26:69–83
Meem RA et al (2021) A Review on the environmental and health impacts due to electronic waste disposal in Bangladesh. GSC Adv Res Rev 8(2):116–125
Moletsane R and Venter C (2018) The 21st century learning environment tools as electronic waste. In: Proceedings of the world congress on engineering and computer science
Murthy V, Ramakrishna S (2022) A review on global E-waste management: urban mining towards a sustainable future and circular economy. Sustainability 14(2):647
Needhidasan S, Samuel M, Chidambaram R (2014) Electronic waste–an emerging threat to the environment of urban India. J Environ Health Sci Eng 12(1):1–9
Nnorom IC, Osibanjo O (2008) Overview of electronic waste (e-waste) management practices and legislations, and their poor applications in the developing countries. Resour Conserv Recycl 52(6):843–858
Omisore AG (2018) Attaining Sustainable Development Goals in sub-Saharan Africa; The need to address environmental challenges. Environmental Development 25:138–145
Otto S et al (2018) The economy of E-waste collection at the individual level: a practice oriented approach of categorizing determinants of E-waste collection into behavioral costs and motivation. J Clean Prod 204:33–40
Pérez-Belis V, Bovea MD, Ibáñez-Forés V (2015) An in-depth literature review of the waste electrical and electronic equipment context: trends and evolution. Waste Manag Res 33(1):3–29
Quinet P, Proost J, Lierde AV (2005) Recovery of precious metals from electronic scrap by hydrometallurgical processing routes. Min Metall Explor 22:17–22
Rautela R et al (2021) E-waste management and its effects on the environment and human health. Sci Total Environ 773:145623
Rucevska I et al (2015) Waste crime–waste risks: gaps in meeting the global waste challenge
Sahajwalla V, Hossain R (2020) The science of microrecycling: a review of selective synthesis of materials from electronic waste. Mater Today Sustain. https://doi.org/10.1016/j.mtsust.2020.100040
Sahle-Demessie E, Glaser J, Richardson T (2018) Electronics waste management challenges and opportunities. American Chemical Society, National Meeting, Boston, MA
Song Q, Li J (2015) A review on human health consequences of metals exposure to e-waste in China. Environ Pollut 196:450–461
Statista (2020) Electronic waste generated worldwide from 2010 to 2019
Sthiannopkao S, Wong MH (2013) Handling e-waste in developed and developing countries: initiatives, practices, and consequences. Sci Total Environ 463:1147–1153
Tanskanen P (2013) Management and recycling of electronic waste. Acta Mater 61(3):1001–1011
Tiseo I (2021) Global E-waste—statistics and facts. Available at: https://www.statista.com/topics/3409/electronic-waste-worldwide/#dossierKeyfigures. Accessed on 27-03-2022
UN News (2013) Environmental and health issues deserve priority in development agenda – UN report, Available at: https://news.un.org/en/story/2013/02/432512, Accessed on 28-03-2022
Wang F et al (2012) The Best-of-2-Worlds philosophy: Developing local dismantling and global infrastructure network for sustainable e-waste treatment in emerging economies. Waste Manag 32(11):2134–2146
Wath SB et al (2010) A roadmap for development of sustainable E-waste management system in India. Sci Total Environ 409(1):19–32
Wto (2020) Committee on technical barriers to trade—notification—Bangladesh—electrical and electronic products. World Trade Organisation
Xia MC et al (2017) Recycling of metals from pretreated waste printed circuit boards effectively in stirred tank reactor by a moderately thermophilic culture. J Biosci Bioeng 123(6):714–721
Zhang S, Forssberg E (1998) Mechanical recycling of electronics scrap—the current status and prospects. Waste Manag Res: J Sustain Circ Econ 16(2):119–128